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SECOND PRELIMINARY REPORT ON NITROGEN OXYGEN SELF-CONTAINED UNDERWATER BREATHING APPARATUS

J. V. Dwyer

Navy Experimental Diving Unit
Washington, D C.

June 1951

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13. ABSTRACT

This report covers an additional investigation into the characteristics and potentialities of the nitrogen-oxygen self-contained underwater breathing apparatus when used under swimming conditions or for extremely heavy work. The original investigation drew the general conclusion that the apparatus is satisfactory as a diving outfit. This evaluation reveals the limitation which develops when the apparatus is used for swimming or heavy work at surface conditions: the unit can produce anoxia. As a result of this limitation, the following guides to use of the unit must be followed:

(1) Use straight oxygen in both bottles for swimming or heavy diving at depths down to 30 feet.

(2) If using the air-oxygen mixture for light diving down to 30 feet, purge the bag completely after every five minutes of unforeseen, sustained, heavy physical exertion.

(3) Use the air-oxygen mixture for swimming or diving at depths greater than 30 feet, and purge the bag completely before starting to the surface.

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WASHINGTON NAVY YARD
WASHINGTON, D.C. 20374

SECOND PRELIMINARY REPORT ON NITROGEN-OXYGEN SELF-CONTAINED UNDERWATER BREATHING EQUIPMENT.

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FOREWORD

A preliminary report on the evaluation of nitrogen-oxygen self-contained underwater breathing apparatus was submitted to the Bureau of Ships on 11 June 1951. Subsequent tests using different techniques for evaluation have produced further information on the apparatus, which is presented here. Pertinent parts of the preliminary report are incorporated directly into this report wherever it is desirable, to minimize cross-reference.

The experimental model evaluated herein is not the production model, which has not yet been made available to the field. However, the two preliminary reports should serve as a helpful guide in determining the characteristics of the production model, which will undergo complete evaluation after arrival

ABSTRACT

This report covers an additional investigation into the characteristics and potentialities of the nitrogen-oxygen self-contained underwater breathing apparatus when used under swimming conditions or for extremely heavy work. The original investigation drew the general conclusion that the apparatus is satisfactory as a diving outfit. This evaluation reveals the limitation which develops when the apparatus is used for swimming or heavy work at surface conditions: the unit can produce anoxia. As a result of this limitation, the following guides to use of the unit must be followed:

(1) Use straight oxygen in both bottles for swimming or heavy diving at depths down to 30 feet.

(2) If using the air-oxygen mixture for light diving down to 30 feet, purge the bag completely after every five minutes of unforeseen, sustained, heavy physical exertion.

(3) Use the air-oxygen mixture for swimming or diving at depths greater than 30 feet, and purge the bag completely before starting to the surface.

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I. OBJECT

This evaluation was made to give additional information on the nitrogen oxygen self-contained underwater breathing apparatus previously evaluated in Report No. 8-51, and in particular to evaluate the apparatus for use as a long-endurance swimming unit.

II. DESCRIPTION

This unit consists of a modified Draegerwerk air-oxygen self-contained underwater breathing apparatus having the following features. Two bottles furnish air and oxygen respectively to a common manifold. From the manifold the mixed gas feeds to a regulator and then to a venturi jet. The venturi discharge leads to the breathing bag, from which the breathing medium circulates to the mask. From the mask the exhaled breathing medium passes to the carbon dioxide absorbent canister. Circulation of the breathing medium through the carbon dioxide absorbent is maintained partly by respiration, but mainly by the aspiration of the venturi, which draws from the absorbent canister and discharges to the breathing bag.

The venturi jet flow is set for surface conditions at 3.1 liters of mixed gas per minute. This particular flow produces a recirculation of the breathing medium of about 65 liters per minute at the surface, decreasing to about 35 at 132 feet of depth. Because of the induced flow, breathing resistance in this apparatus is extremely low. Because of the constant jet supply, containing a percentage of inert gas which is not utilized by the breathing process, a constant excess of gas is built up in the breathing bag. The excess is discharged through a pop-off valve located on the bag proper, set at 2.5 inches of water pressure.

The apparatus has the following characteristics:

(1) The air and oxygen bottles are of the same size, 2.0 liters internal capacity, and hold 274 liters of free gas each when charged to 2000 psig.

(2) The regulator is adjusted to 110 psig over bottom pressure.

(3) The breathing bag has a capacity of 5.1 liters.

(4) The absorbent canister has a capacity of approximately 5 pounds of absorbent.

(5) Several masks were used with this apparatus, principally the MSA bug-eye type.

III. PROCEDURE

A. Original evaluation

1. The original evaluation encompassed 78 dives at varying depth under various conditions of work, and some swimming runs not included in the evaluation. For some dives moderately heavy work was simulated by lifting a 68.5-pound weight through a distance of 27-1/4 inches 5 times a minute for 10-minute work periods alternating with 5-minute rest periods. Breathing medium analysis samples were drawn by Luer syringe and analyzed on a Haldane apparatus.

2. The swimming runs were made primarily to determine the balance and comfort of the apparatus, and samples were not taken.

B. Present evaluation

1. The present evaluation encompassed 11 swimming runs at a rate of 1 knot under carefully controlled conditions in the open pool. Some of the runs were sampled by the original method; the remainder were evaluated by the return-sample method using the instantaneous carbon dioxide analyzer and the Beckman and Scholander oxygen analyzers.

2. The two diving runs were made at 33 and 66 feet of depth, and were sampled by the pressure return-sampling apparatus shown schematically in figure 12. In this method, a breathing bag sample was led continuously to the outside of the pressure tank, through a water washer, and into a bladder. Samples for oxygen and carbon dioxide analyses were drawn by syringe, and were analyzed on the Scholander and Haldane analyzers respectively. Periodically, as the bladder became inflated, the accumulated breathing medium was returned through the tank to the mask exhalation tube by an electrically driven diaphragm pump. These returns were made sufficiently frequently that the inflation of the breathing bag as a result of the additional gas volume was negligible, and the breathing medium was essentially unaffected.

IV. RESULTS

A. Swimming runs

Eleven swimming runs were made with the N2-02 apparatus. The results are shown graphically in figures 1 through 11.

1., Run #1 (figure 1) was made before the continuous-sampling method was developed, and has somewhat sketchy data. In addition, the bottles were recharged between swimmers, so that essentially this is two different runs. However, some points of interest are apparent upon examination of the graph. In one hour of swimming the first subject had reduced the oxygen percentage to 38%. In one hour and a quarter the second had reduced the oxygen to 20%. The absorbent was not changed between swimmers, and in the total apparatus time of 2:15 the bag carbon dioxide had built up to 0.7%.

2. Run #2 (figure 2) was also made with the old sampling procedure. Its sàlient features are: the markedly lower oxygen percentage from that of the theoretical input; the continued drop of oxygen percentage during the later part of the run; the low carbon dioxide percentage up to 2:00; and the sharp rise of carbon dioxide percentage after 2:30.

3. Run #3 (figure 3) was the last run made with the old procedure. Salient features are: the marked oxygen drop up to 1:00; the sharp oxygen rise from 1:00 to 1:30, and steady fall from 1:30 to 2:30; and the gradual carbon dioxide rise.

4. Run #4 (figure 4) was made with pure oxygen in both bottles, to give an indication of the potentialities of the apparatus for use as a straight oxygen SCUBA. Oxygen percentages are shown in data sheet 4 but not in figure 4. Salient features of the graph are: the low carbon dioxide percentage throughout the entire run; and the possible break in the curve at 2:30. The apparatus ran out of gas at 2:47; the venturi flow of 3.1 liters per minute is materially in excess of the oxygen requirements of a swimmer.

5. Run #5 (figure 5) was made using the return-sampling procedure. Salient features are: the drastic reduction of oxygen percentage throughout each section of the swimming run (which was made by three men in succession); the rise (probable and actual) of oxygen percentage at each change of swimmers; the low carbon dioxide percentage during the first 1:30 of the run; and the continuous rise of carbon dioxide after that time.

6. Run #6 (figure 6) shows: a reasonably high oxygen percentage, with a tendency to drop off in the later part of the swim; and a gradual build-up of carbon dioxide.

7. Run #7 (figure 7) shows: the tendency of each swimmer to pull the oxygen level down; and the nearly constant carbon dioxide level throughout the run.

8. Run #8 (figure 8) shows: a steady decrease in oxygen for the first swimmer; and a probable anoxic condition for the second, whom accumulated data indicate as having a high oxygen uptake rate. Unfortunately a sample was not taken immediately upon his being pulled from the water, and the continuing jet flow increased the oxygen content in the bag.

9. Run #9 (figure 9) shows: a gradual oxygen depletion for the first swimmer; and a faster depletion for the second.

10. Run #10 (figure 10) shows: a high oxygen level for the first swimmer; and a depletion to anoxia for the second.

11. Run #11 (figure 11) shows: a gradual oxygen depletion for the first swimmer; and a rapid depletion for the second.

B. Tank dives

Two tank dives were made with the apparatus, at a depth or 33 feet and of 66 feet. The results are shown graphically in figures 13 and 14.

1. Dive #1 (figure 13) was made at the 33-foot depth using the return-sampling method. Salient features are: the marked rise of oxygen percentage during rest periods,; the rise and fall of oxygen percentage during weight-lifting periods; and the sharp decrease of oxygen percentage during cycling.

2. Dive #2 (figure 14) was made at the 66-foot depth under conditions as close as possible to those of dive #1, including use of the same subject. Because of a fouled breathing tube, however, the cycling portion of the run was not duplicated completely.

C. Venturi flow and oxygen level

As a consequence of the foregoing results, a check of the venturi jet flow at depth and a theoretical analysis of the breathing medium oxygen level under various conditions were made.

1. The venturi jet flow at various depths was measured by spirometer in the recompression chamber. The data and computations are shown on data sheet 14, and the results are shown graphically in figure 15.

2. Data sheet 15 shows the calculation of theoretical oxygen level in the N_2-O_2 apparatus for surface conditions at various oxygen uptake rates with the venturi jet set at its normal 3.1 liters per minute flow. Figure 16 shows the results graphically.

3. Data sheet 16 shows the calculation of theoretical oxygen level in the apparatus at surface conditions at various oxygen uptake rates with the venturi jet set in increments of 0.20 from 3.00 to 4.60 liters per minute.

V. DISCUSSION

A. Swimming runs

Careful examination of the swimming data indicates that in this apparatus under swimming conditions it is possible to reduce the oxygen content of the breathing medium far below a safe level for sustention of life. In every case that a swimmer exerted himself greatly while wearing the apparatus, he immediately induced a rapid depletion of the oxygen content. Even in the case of a well-trained, physically fit, experienced swimmer who could control his exertion and breathing and thereby keep his oxygen uptake low, the onset of fatigue in an hour or so led to increased exertion which produced a gradual depletion of oxygen, and in some instances produced a sudden depletion leading to anoxia without warning.

In the single run of the apparatus as a straight oxygen SCUBA the unit performed fully as well as any other straight oxygen SCUBA tested here, if not better. Oxygen content remained high, carbon dioxide content remained low, and exhaustion occurred only when the apparatus ran out of gas at two hours and forty-seven minutes. Potentially, the apparatus could be used in the field as a straight oxygen SCUBA without modification. With modification of the venturi to give a reduced flow (say two liters per minute), running time could be extended considerably, although design thought would have to be given to the increase of breathing resistance caused by the lessened recirculation.

In every case the carbon dioxide content remained satisfactorily low for at least two hours. This condition is a natural consequence of the forced recirculation of the exhaled breathing medium and of the large 5 pounds absorbent capacity of the canister.

B. Tank dives

Examination of the diving data bears out the conclusions made in the first preliminary report that the apparatus is satisfactory for use in diving under conditions of exercise similar to those simulated by weight lifting, such as might attain for exploratory diving and light work in a calm harbor. Further examination, however, reveals that the apparatus can become hazardous under conditions of sustained and heavy exercise similar to those simulated by cycling, such as might attain for heavy diving at shallow depths in a seaway with a strong tide running. At deeper depths the increased surface equivalent jet flow and the increased equivalent surface oxygen percentage eliminate danger of anoxia.

Unfortunately, a malfunction of the apparatus after the second dive prevented accumulation of further substantiating data along these lines. Nevertheless, a positive statement can be made that duplication of the results will occur for any duplication of the conditions.

C. Venturi flow and oxygen level

1.. Venturi jet flow

As indicated in the first report, the jet flow (for surface conditions) increases with increasing depth. For the particular measuring run of data sheet 14 and figure 15, a maximum flow of 0.91 liters per minute (equivalent to a surface flow of 4.57 liters per minute) attained at 132 feet (five atmospheres total pressure). From table 9 of data sheet 16, this flow would satisfy the needs of an oxygen uptake rate of 2.50 liters per minute at surface conditions, with a safety factor of 5 for the 132-foot depth. This oxygen uptake rate could be produced only by the most extreme exertion, as in a runner making a mile in four minutes. Even at the 33-foot depth, with an equivalent surface flow of 3.33 liters per minute, interpolation between tables 2 and 3 of data sheet 16 indicates that an oxygen uptake rate of about 1.75 liters per minute would maintain an oxygen level of 13%, with a safety factor of 2 for the depth. This oxygen uptake rate is about that of a well-fatigued swimmer still making one knot.

The foregoing indicates in essence that the apparatus produces an anoxia hazard mainly at surface conditions of continuing strenuous exertion, and that it tends to become increasingly less hazardous at depth. However, it should be borne in mind that sudden return to the surface reduces the safety factor to one (that is, to no safety at all). If the diver has reduced the oxygen level to a point that the depth safety factor is the means whereby he has a sufficiency of oxygen, sudden return to the surface will immediately induce an anoxia condition with no warning whatsoever.

One feature peculiar to the apparatus works in favor of anyone overcome by anoxia through depletion of breathing medium oxygen. Cessation of muscular exertion with unconsciousness allows the continuing jet flow to increase the oxygen level immediately. Figure 13 shows an oxygen increase rate of nearly two percent per minute in the last rest period, after the oxygen had been depleted close to 17%. From the anoxia conditions which discontinued run #2 (7.19% oxygen), three minutes at this rate would have increased the oxygen level to 13%. This increase might serve to revive a diver at shallow depths. Increased effective oxygen percentage caused by increased depth might help revive an unconscious swimmer falling to depth from surface conditions, but the attendant squeeze would be serious.

2. Oxygen level

Data sheet 15 and figure 16 show in tabular and graphic form the theoretical oxygen level at surface conditions in the apparatus for various oxygen uptake rates with a 3.1 liter per minute jet flow. The graph in particular gives a striking picture of the increasing depletion rate at the higher uptake rates (the depletion rate is represented by the negative slope of the curve, which increases sharply above the 1.00 liter per minute uptake rate). It also indicates clearly that a swimmer with an uptake rate of 1.50 liters per minute will always have more than enough oxygen at 23% but that another swimmer with an uptake rate of 1.70 liters per minute will qickly reduce the breathing medium oxygen level dangerously close to anoxia at 15%. By increasing his uptake rate a mere 0.05 liters per minute for any continued period the second swimmer will reduce the level below 10%.

Data sheet 16 and figure 17 shows the logical extension of the foregoing analysis to cover a series of jet flow rates from 3.00 to 4.60 liters per minute supply. If an oxygen level of 17% is taken as minimum acceptable, and if an uptake rate of 2.00 liters per minute is taken as maximum probable, then table 5 indicates that a minimum jet flow of just over 3.80 liters per minute should be used. A cross-curve of the 2.00 liter per minute uptake rate from tables 3 through 9 would allow selection of the jet flow to produce any desired minimum oxygen level at a 2.00 liter per minute uptake rate.

VI. CONCLUSIONS

The nitrogen-oxygen self-contained underwater breathing apparatus has the following advantages and disadvantages, as summarized in the first report.

A. Advantages

1. Long duration for a self-contained apparatus.
2. Comfortable in comparison with similar units.
3. No gas mixing or gas analysis is required.
4. Easy to use and requires little additional diving training.
5. Very light and can be used from small craft easily.
6. No purging required.
7. No carbon monoxide poisoning danger as in the case of portable air compressor.
8. The oxygen curve of this unit is so shaped that it is possible to use it for comparatively long dives with little danger of oxygen poisoning.
9. It is quiet in operation.
10. Telephone communication is good.
11. Need for decompression is decreased.

12. It can be used with the current modified Desco suit and hence the manufacture of special dress is not required.

13. The danger of a fast blow-up is eliminated. A blow-up can be safely used in the event of an emergency.

14. The breathing apparatus can be adapted to a swim suit.

15. This unit is completely independent in operation and hence no compressor or large banks are required, having previous charged compressed air and oxygen bottles to 1800 psi.

16. It is non-magnetic when used with the aluminum bottles.

B <u>Disadvantages</u>

1. Somewhat more complicated than a conventional suit.

2. Carbon dioxide absorbent required such as soda lime or Baralyme.

3. Facilities must be available for the filling of bottles with compressed air and oxygen.

4. Limited duration at greater depths due to possibility of oxygen poisoning.

The foregoing advantages and disadvantages still apply to use of the apparatus as a diving unit. In addition, the following disadvantage applies to use of the apparatus as a swimming unit: The apparatus can produce anoxia.

C.. <u>Conclusion</u>

The units which are presently under procurement should be evaluated with special attention to the following facts:

1. In their present design, the units may be extremely hazardous for swimming under field conditions.

2. When used for swimming or heavy diving to depths not greater than 30 feet, the apparatus should be used as a straight oxygen SCUBA.

3. When used for light diving down to 30 feet, the apparatus can be used as a mixed-gas outfit, but special care should be taken to note any unforeseen, prolonged physical exertion, and to purge the bag every five minutes during this period.

4. When used for swimming to depths greater than 30 feet, the apparatus can safely be used as a mixed-gas SCUBA by purging the bag completely with the bypass before commencing ascent.

5. Based on present analysis and evaluation this unit is adaptable both to diving and to swimming under the foregoing specification.

VII. DATA SHEETS

1. Swimming run #1, 6 March 1952
2. Swimming run #2, 7 March 1952
3. Swimming run #3, 10 March 1952
4. Swimming run #4 (straight oxygen), 29 April 1952
5. Swimming run #5, 30 April 1952
6. Swimming run #6, 9 July 1952
7. Swimming run #7, 10 July 1952
8. Swimming run #8, 14 July 1952
9. Swimming run #9, 15 July 1952
10. Swimming run #10, 16 July 1952
11. Swimming run #11, 17 July 1952
12. Tank dive #1 (33 feet), 19 June 1952
13. Tank dive #2 (66 feet), 23 June 1952
14. Venturi jet flow at various depths, 7 July 1952
15. Theoretical oxygen level at 3.1 liter per minute flow
16. Theoretical oxygen level at various flows

Type: N202	Depth: Surface	Location: Pool
Start: 0834	Stop: 0934	Total time: 1-00
Pressure: 1700 psig	Pressure: 800 psig	Absorbent: Soda lime
Start: 0948	Stop: 1103	Total time: 1-15
Pressure: 1650 psig	Pressure: 800 psig	Absorbent: Soda lime

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
1-00	37.77	0.072	Stevens Off Recharged bottles
1-30	31.57	0.354	Bohline on
2-00	29.50	0.172	
2-15	20.33	0.686	Bohline off

Recharged bottles between swimmers. Samples drawn with Luer syringe and analyzed on Haldane apparatus.

Run #1
6 March 1952

Data Sheet 1

Type: N202

Depth: Surface

Location: Pool

Start: 0815

Stop: 1119

Total time: 3-01

Pressure: 2250 psig

Pressure: 150 psig

Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
1-00	38.66	1.08	Inhalation tube sample
1-30	38.67	0.06	Bag sample
2-00	30.33	0.22	
2-30	12.80	0.38	
3-00	7.19	1.91	

Baralyme 95% discolored.

Run #2
7 March 1952

Type: N202

Start: 0855

Pressure: 1900

Depth: Surface

Stop: 1136

Pressure: 340

Location: Pool

Total time: 2-37

Absorbent: Soda lime

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
1-00	12.43	0.15	
1-01			Changed swimmers
1-30	35.95	0.17	
1-45			Changed swimmers
2-00	31.27	0.11	
2-15	31.27	0.19	
2-30	25.77	0.22	
2-37			Secured run Sodalime 50% discolored.

Run #3
10 March 1952
Data Sheet 3

Type: N202 | Depth: Surface | Location: Pool

Start: 1255 | Stop: 1542 | Total time: 2-47

Pressure: 2250 psig | Pressure: 0 psig | Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-16	88	0.06	MC KENZIE on
0-30	94	0.09	
0-45	96	0.09	
0-48	-	-	Off bag
0-54	-	-	STEVENS on
1-00	80	0.09	
1-15	90	0.03	
1-30	90	0.13	
1-45	90	0.13	
1-47	-	-	Off bag
1-54	-	-	MOORE on
2-00	88	0.30	
2-15	90	0.19	
2-30	90	0.23	
2-45	88	0.53	
2-47	-	-	Off bag. Out of gas

Both bottles charged with straight oxygen.

Run #4
29 April 1952

Data Sheet 4

Type: N2O2 | | Depth: Surface | | Location: Pool
---|---|---
Start: 1322 | Stop: 1605 | Total time: 2-43
Pressure: 2100 | Pressure: 0 | Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-15	34	0.06	FEGAN on
0-30	28	0.06	
0-45	28	0.06	
1-00	22	0.06	
1-02	-	-	Off bag
1-05	-	-	MC KENZIE on
1-15	27	0.16	
1-30	26	0.19	
1-45	21	0.41	
2-00	13	0.69	
2-02	-	-	Off bag
2-03	29	-	MOERSCH on
2-15	27	1.06	
2-30	27	0.91	
2-43	20	-	Secured run. Swimmer had breathing trouble.

Run #5
30 April 1952

Data Sheet 5

Type: N202	**Depth:** Surface	**Location:** Pool
Start: 0842	**Stop:** 1104	**Total time:** 2-10
Pressure: 2000 psig	**Pressure:** -	**Absorbent:** Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-18	54	0.10	STEVENS on
0-31	50	0.14	
0-49	52	0.23	
1-01	49	0.55	
1-03	-	-	Off bag
1-15	-	-	KISSEE on bag
1-30	48	0.22	
1-45	49	0.22	
2-00	41	0.29	
2-05	44	-	
2-10	41	-	
2-15	43	0.33	
2-22	-	-	Off bag

Run #6
9 July 1952

Data Sheet 6

Type: N2O2 | Depth: Surface | Location: Pool

Start: 0830 | Stop: 1104 | Total time: 2-34

Pressure: 2000 psig | Pressure: 100 psig | Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-15	45	0.25	GRIFFITH on
0-30	47	0.12	
0-45	44	0.25	
1-00	41	0.19	
1-02	--	---	Off bag
1-05	--	---	YENTES on
1-20	32	0.29	
1-27	--	---	Off bag
1-32	--	---	MOERSCH on
1-47	44	0.33	
2-02	41	0.33	
2-17	38	0.33	
2-32	31	0.33	
2-34	--	---	Off bag. Secured run.

Run #7
10 July 1952

Data Sheet 7

Tpye: N202 | Depth: Surface | Location: Pool

Start: 0843 | Stop: 1019 | Total time: 1-37

Pressure: 2000 psig | Pressure: 900 psig | Absorbent: Baralyme

TIME h m	EXHALATION OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-15	32	0.15	MC ARDLE on
0-31	35	0.09	
0-38	39	---	Bag sample
0-46	25	0.15	
0-50	32	---	
1-00	26	0.12	
1-15	22	0.26	
1-17	--	---	Off bag
1-21	--	---	FEGAN on
1-37	27	---	Off bag

Last swimmer showed high respiratory rate; fingernails and face were blue from probable anoxia. Oxygen sample at 1-37 is high because of continuing venturi flow; actual medium breathed could possibly have been very anoxic.

Run #8
14 July 1952

Data Sheet 8

Type: N202 Depth: Surface Location: Pool

Start: 0852 Stop: 1050 Total time: 1-57

Pressure: 2000 psig Pressure: 0 psig Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-15	48	0.05	STEVENS on
0-30	50	0.05	
0-45	53	0.05	
1-00	46	0.05	
1-15	45	0.05	
1-30	43	0.05	Off bag
1-37	--	---	LEWIS on
1-52	35	0.05	
1-56	--	---	Respiratory difficulty
1-57	--	---	Secured run; zero pressure.

Run #9
15 July 1952

Data Sheet 9

Type: N202 | Depth: Surface | Location: Pool

Start: 0845 | Stop: 1046 | Total time: 1-41

Pressure: 2000 psig | Pressure: 325 psig | Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-02	44	0.07	LEWIS on
0-15	46	0.07	
0-30	44	0.07	
0-45	39	0.07	
1-00	44	0.07	
1-02	--	---	Off bag
1-05	--	---	FEGAN on
1-20	38	0.07	
1-29	23	---	
1-34	21	---	
1-39	12	0.09	Near anoxia
1-41	--	---	Off bag. Secured run.

Run #10
16 July 1952

Data Sheet 10

Type: N202 Depth: Surface Location: Pool

Start: 0836 Stop: 1009 Total time: 1-33

Pressure: 1975 psig Pressure: 550 psig Absorbent: Baralyme

TIME h m	BAG OXYGEN percent	CARBON DIOXIDE percent	REMARKS
0-05	41	----	MOERSCH on
0-10	46	----	
0-20	44	----	
0-30	46	0.12	
0-40	47	----	
0-50	42	----	
1-00	37	0.12	
1-02	--	----	Off bag
1-06	--	----	DWYER on
1-17	32	----	
1-27	16	----	
1-33	16	----	Off bag. Secured run.

Run #11
17 July 1952

Data Sheet 11

Type: N202 | Depth: 33 feet | Location: Tank

Start: 0915 | Stop: 1024 | Total time: 1h 09m

Pressure: Not observed | Absorbent: Sodalime

Flow: 3.2 liters per minute at surface | Diver: FEGAN

TIME h m	OXYGEN percent	REMARKS
0-00	32.65	Start resting
0-05	37.83	Start weight lifting
0-10	39.90	
0-15	39.90	Start resting
0-20	44.05	Start weight lifting
0-25	41.95	
0-30	40.94	Start resting
0-35	44.05	Start exercycling
0-39	39.90	
0-42	34.72	
0-45	31.61	
0-48	26.42	
0-51	22.28	
0-54	20.28	
0-57	18.14	
1-00	17.10	Start resting
1-03	22.28	
1-06	29.54	
1-09	33.68	Secure run

Dive #1
19 June 1952

Type: N2O2 | Depth: 66 feet | Location: Tank

Start: 0905 | Stop: 1000 | Total time: 0h 45m

Pressure: Not observed | Absorbent: Sodalime | Diver: FEGAN

Flow: 3.2 liters per minute at surface.

TIME h m	OXYGEN percent	REMARKS
0-00	45.53	Start resting
0-02 1/2	57.87	
0-05	53.76	Start weight lifting
0-10	52.73	
0-15	51.55	Start resting
0-20	52.58	Start weight lifting
0-25	50.52	
0-30	49.49	Start resting
0-35	50.52	Start exercycling
0-40	46.40	
0-45	38.15	
0-46	Secured run - breathing tube fouled.	

Dive #2
23 June 1952

Data Sheet 13

VENTURI JET FLOW
in N202 SCUBA
at various depths
measured in recompression chamber
by spirometer

D DEPTH feet	r FACTOR ratic	t TIME seconds	s SCALE mm	d DISPL, cc	f ACUTAL FLOW lpm	F SURFACE FLOW lpm
132	5	273.0	200	4180	0.91	4.57
99	4	123.0	100	2090	1.02	4.07
99	4	248.4	200	4180	1.00	4.02
66	3	99.0	100	2090	1.26	3.78
66	3	202.0	200	4180	1.24	3.71
33	2	75.0	100	2090	1.67	3.33
0	1	41.0	100	2090	3.04	3.04
0	1	83.0	200	4180	3.01	3.01
0	1	123.0	300	6270	3.04	3.04

$$f = (20.8)\ (s)\ (60/t)$$
$$F = (r)\ (f)$$

7 July 1952

Data Sheet 14

THEORETICAL OXYGEN LEVEL
IN N202 SCUBA
for surface conditions
at various oxygen uptake rates
with venturi jet at 3.1 liters per minute flow

$$x = ((p - x)/(f - x))(100), \quad \text{where}$$

f = venturi jet flow, 3.10 liters per minute
p = oxygen supply, 1.87 liters per minute
x = oxygen uptake rate, liters per minute
x = theoretical oxygen level, percent

x	p-x	f-x	x
0.00	1.87	3.10	60.5
0.30	1.57	2.80	56.1
0.50	1.37	2.60	52.7
0.80	1.07	2.30	46.5
1.00	0.87	2.10	41.4
1.20	0.67	1.90	35.2
1.40	0.47	1.70	27.6
1.60	0.27	1.50	18.0
1.80	0.07	1.30	5.8
1.86	0.00	1.24	0.0

11 July 1952
Data Sheet 15

THEORETICAL OXYGEN LEVEL IN N202 SCUBA
for surface conditions at various venturi jet flow and various oxygen uptake rates

Table	1	2	3	4	5	6	7	8	9
f	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60
p	1.82	1.94	2.06	2.18	2.30	2.42	2.54	2.66	2.78

f - venturi jet flow, liters per minute
p - oxygen supply, liters per minute
x - oxygen uptake, liters per minute
x - oxygen level, percent

Table 1

x	p-x	f-x	x
0.00	1.82	3.00	60.5
0.50	1.32	2.50	52.7
1.00	0.82	2.00	41.0
1.50	0.32	1.50	21.3
1.82	0.00	1.18	0.0
2.00	-	-	-
2.50	-	-	-

Table 2

x	p-x	f-x	x
0.00	1.94	3.20	60.5
0.50	1.44	2.70	53.3
1.00	0.94	2.20	41.7
1.50	0.44	1.70	25.9
1.94	0.00	1.26	0.0
2.00	-	-	-
2.50	-	-	-

Table 3

x	p-x	f-x	x
0.00	2.06	3.40	60.5
0.50	1.56	2.90	53.8
1.00	1.06	2.40	44.2
1.50	0.56	1.90	29.5
2.00	0.06	1.40	2.3
2.06	0.00	1.34	0.0
2.50	-	-	-

Table 4

x	p-x	f-x	-x
0.00	2.18	3.60	60.5
0.50	1.68	3.10	54.2
1.00	1.18	2.60	45.4
1.50	0.68	2.10	32.4
2.00	0.18	1.60	11.2
2.18	0.00	1.10	0.0
2.50	-	-	-

Table 5

x	p-x	f-x	x
0.00	2.30	3.80	60.5
0.50	1.80	3.30	54.5
1.00	1.30	2.80	46.4
1.50	0.80	2.30	34.8
2.00	0.30	1.80	16.7
2.30	0.00	1.30	0.0
2.50	-	-	-

Table 6

x	p-x	f-x	x
0.00	2.42	4.00	60.5
0.50	1.92	3.50	54.9
1.00	1.42	3.00	47.3
1.50	0.92	2.50	36.8
2.00	0.42	2.00	21.0
2.42	0.00	1.58	0.0
2.50	-	-	

Table 7

x	p-x	f-x	x
0.00	2.54	4.20	60.5
0.50	2.04	3.70	55.1
1.00	1.54	3.20	48.1
1.50	1.04	2.70	38.5
2.00	0.54	2.20	24.6
2.50	0.04	1.70	2.4
2.54	0.00	1.66	0.0

Table 8

x	p-x	f-x	x
0.00	2.66	4.40	60.5
0.50	2.16	3.90	55.4
1.00	1.66	3.40	48.8
1.50	1.16	2.90	40.0
2.00	0.66	2.40	27.5
2.50	0.16	1.90	8.4
2.66	0.00	1.74	0.0

Table 9

x	p-x	f-x	x
0.00	2.78	4.60	60.5
0.50	2.28	4.10	55.7
1.00	1.78	3.60	49.4
1.50	1.28	3.10	41.3
2.00	0.78	2.60	30.0
2.50	0.28	2.10	13.3
2.78	0.00	1.82	0.0

$$x = ((p - x)/(f - x))(100)$$

14 July 1952

Data Sheet 16

VIII. FIGURES

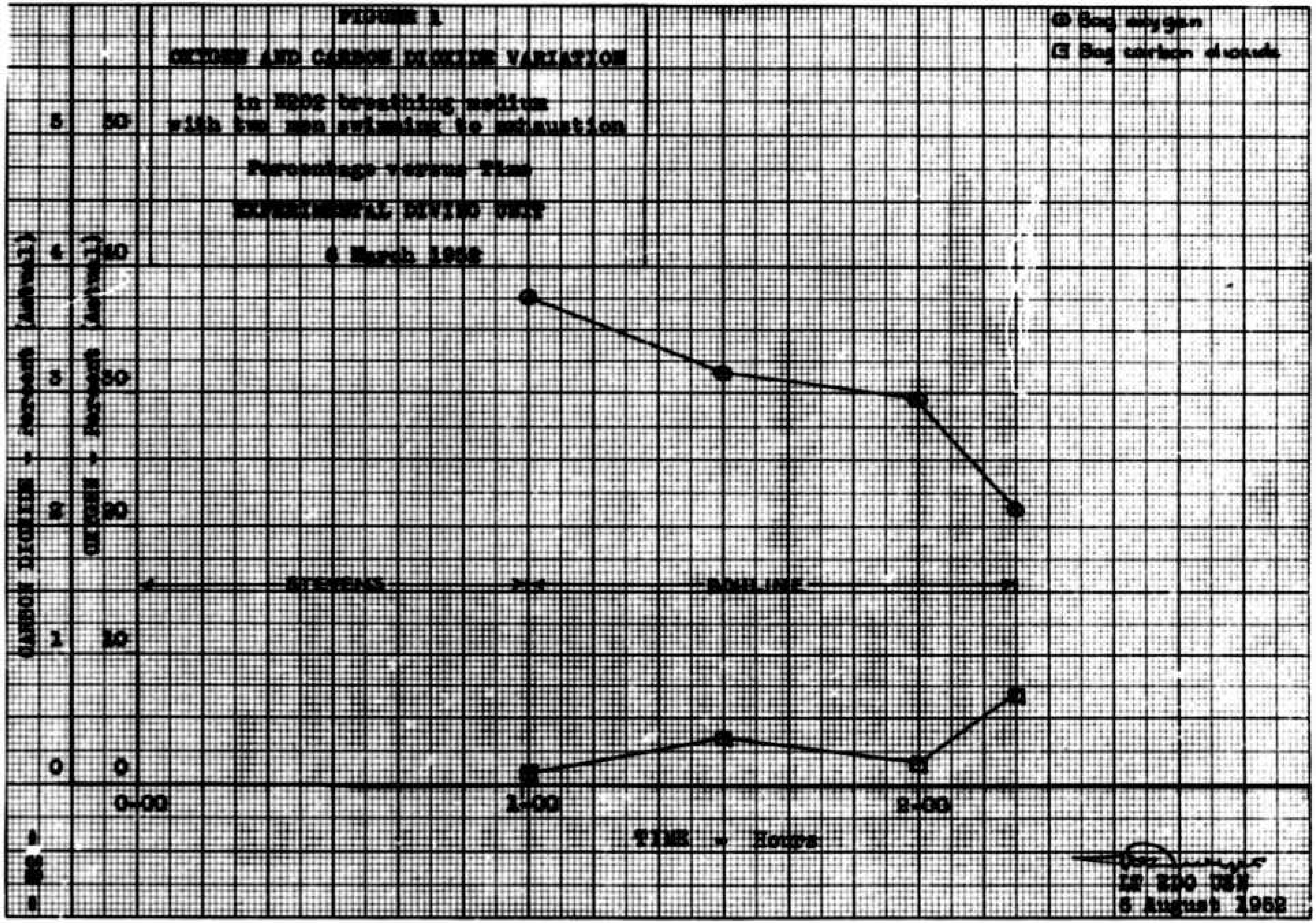


FIGURE 1
OXYGEN AND CARBON DIOXIDE VARIATION
in HeO2 breathing medium
with two men swimming to exhaustion
Percentage versus Time
EXPERIMENTAL DIVING UNIT
6 March 1962
Bag oxygen
Bag carbon dioxide
CARBON DIOXIDE - Percent (Actual)
OXYGEN - Percent (Actual)
STEVENS
BOWLINE
0:00
1:00
2:00
TIME - Hours
LT EDO USN
6 August 1962

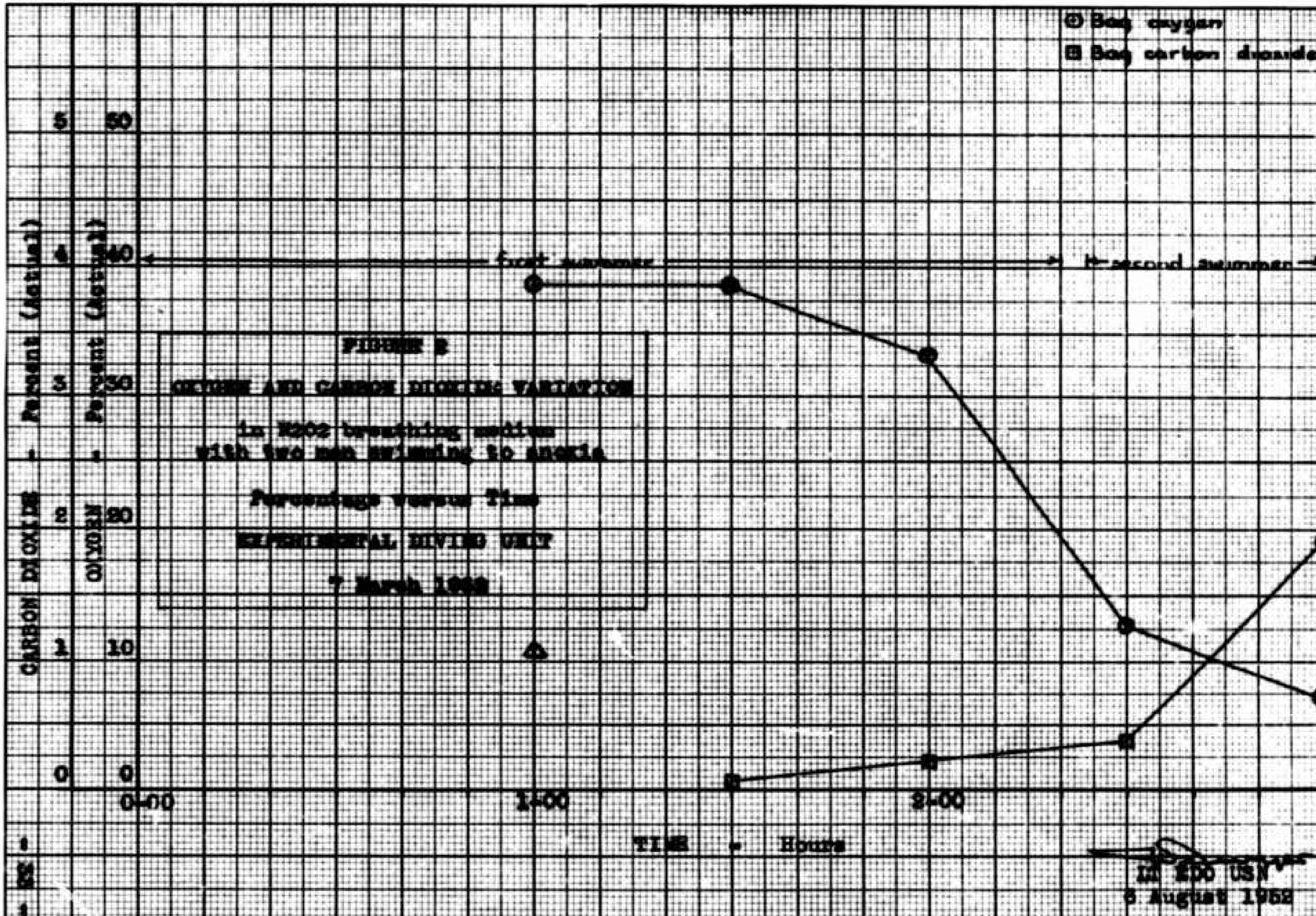


FIGURE 2

OXYGEN AND CARBON DIOXIDE VARIATION

in N2O2 breathing medium
with two men swimming to anoxia

Percentage versus Time

EXPERIMENTAL DIVING UNIT

7 March 1952

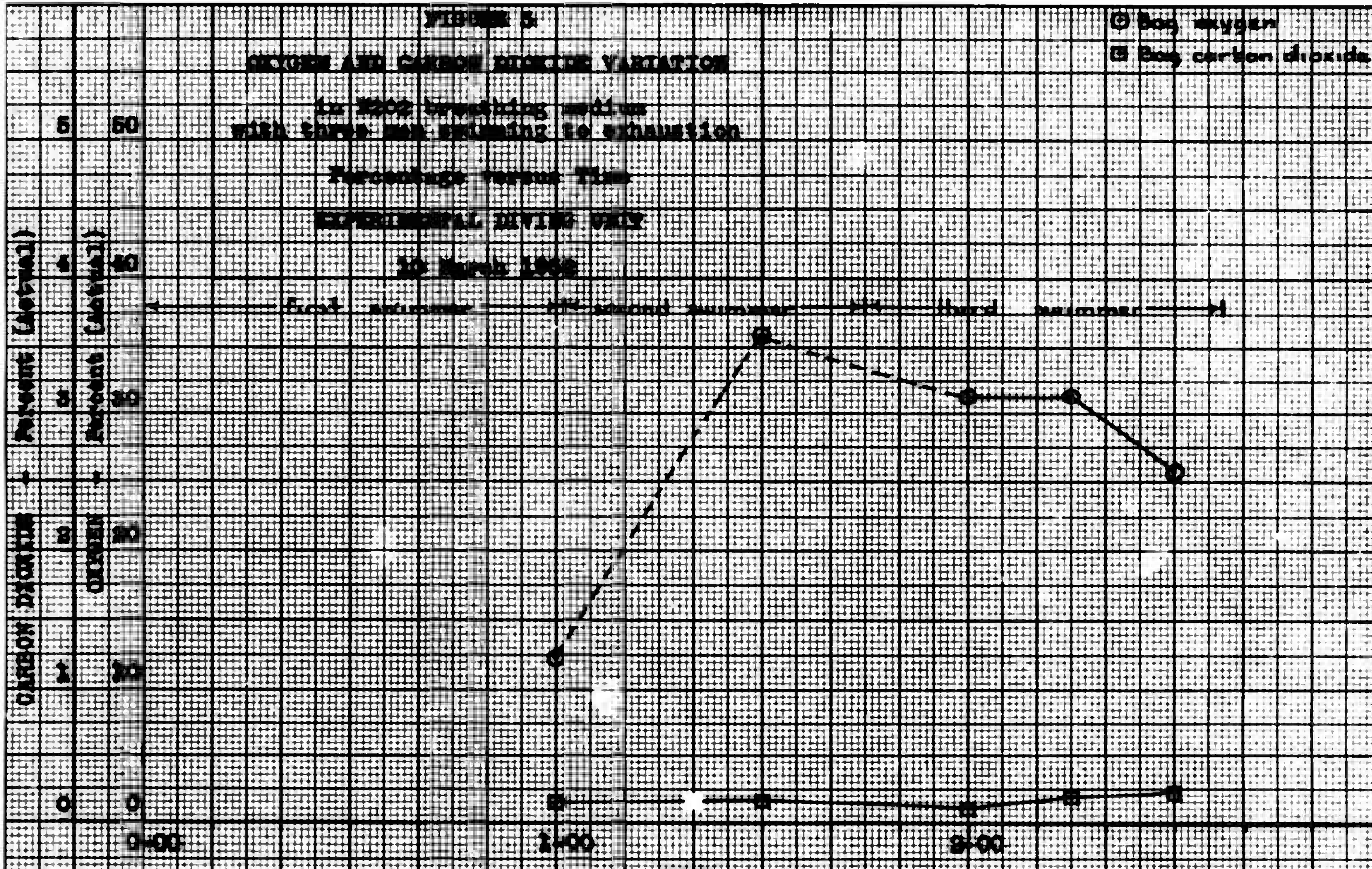


FIGURE 5
OXYGEN AND CARBON DIOXIDE VARIATION
with three men swimming to exhaustion
Percentage versus Time
EXPERIMENTAL DIVING UNIT
first swimmer
second swimmer
third swimmer
Bag oxygen
Bag carbon dioxide
CARBON DIOXIDE - Percent (Actual)
OXYGEN - Percent (Actual)
0
1
2
3
4
5
0
10
20
30
40
50
0:00
1:00
2:00
TIME - Hours
6 August 1952

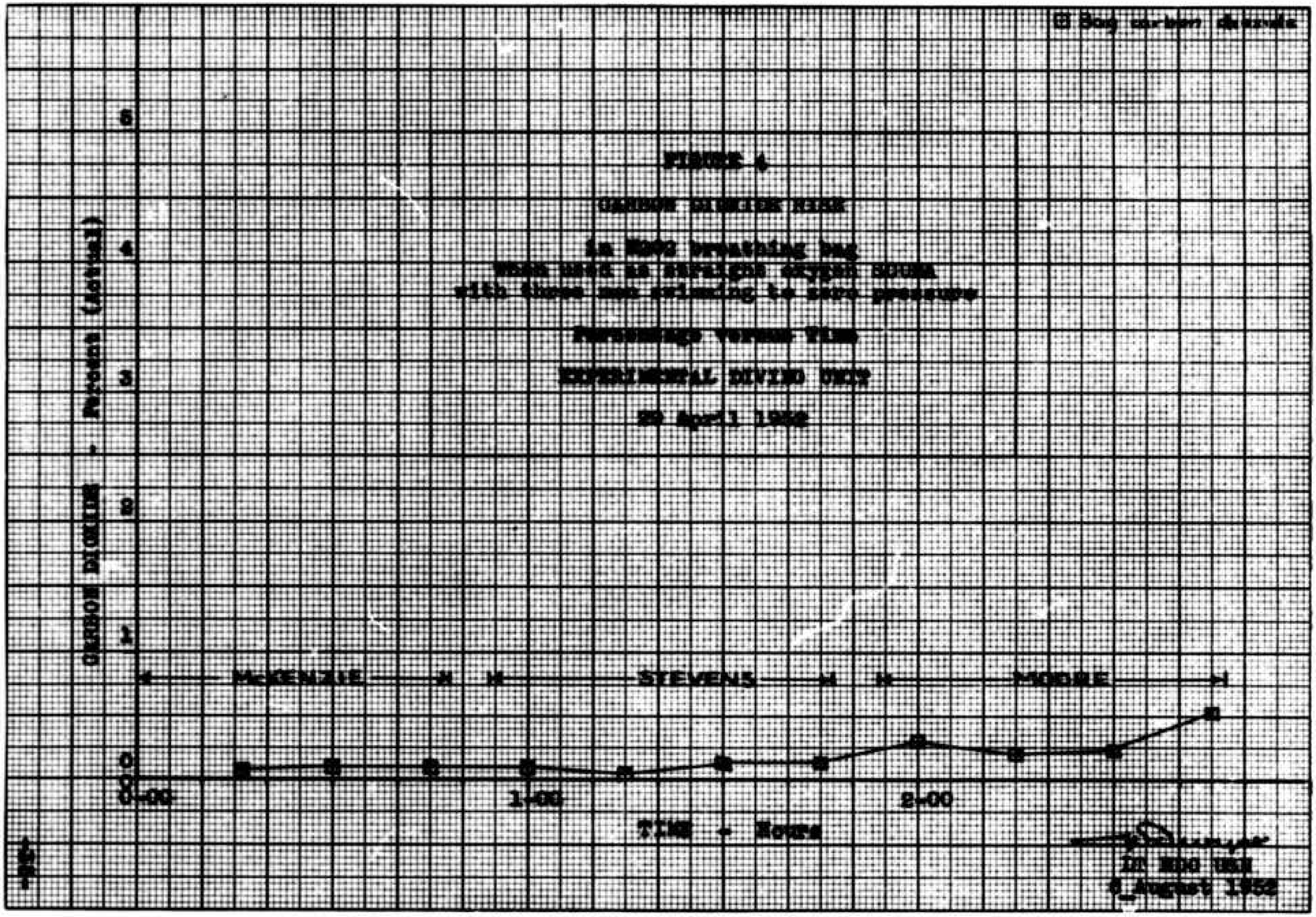
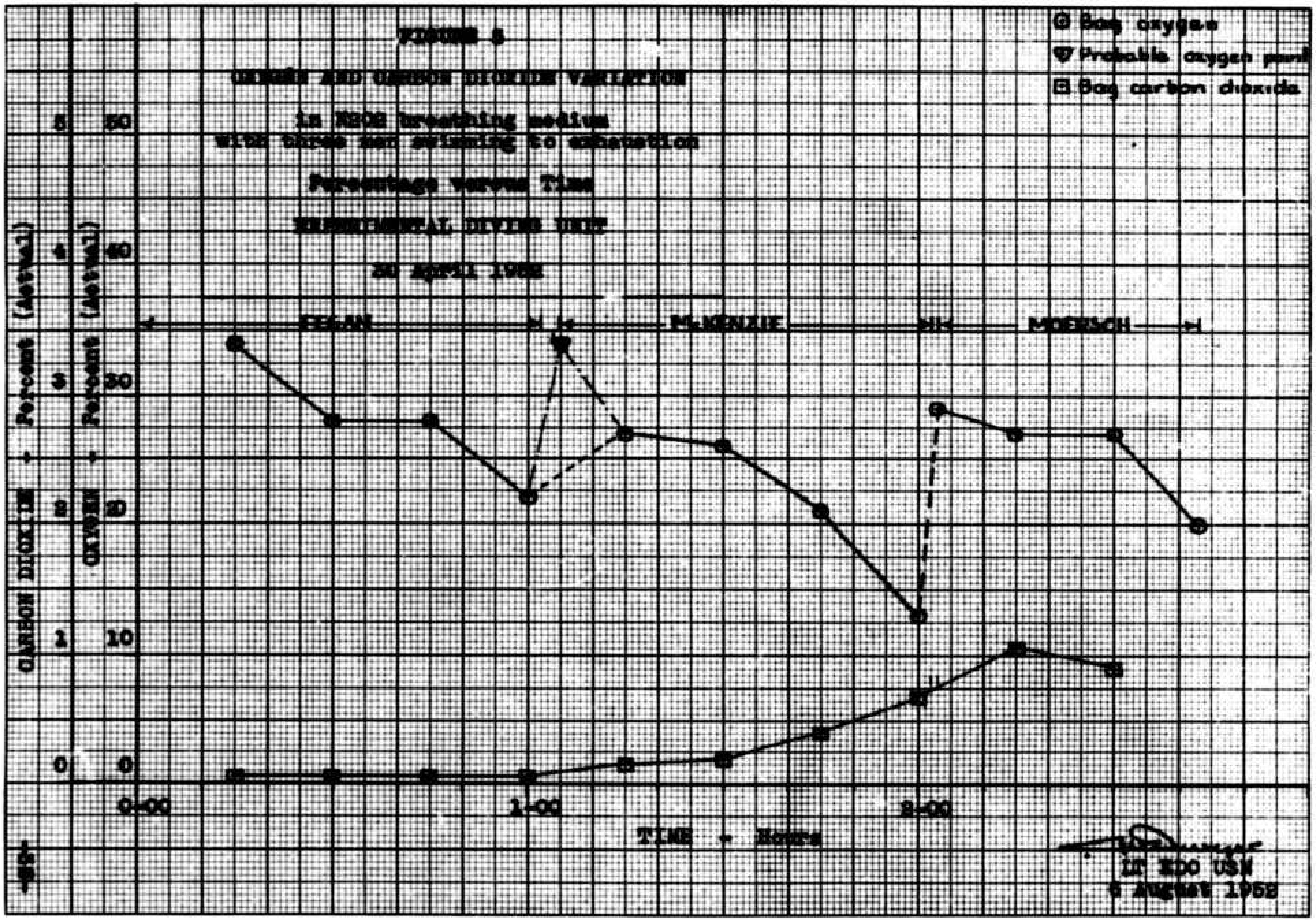
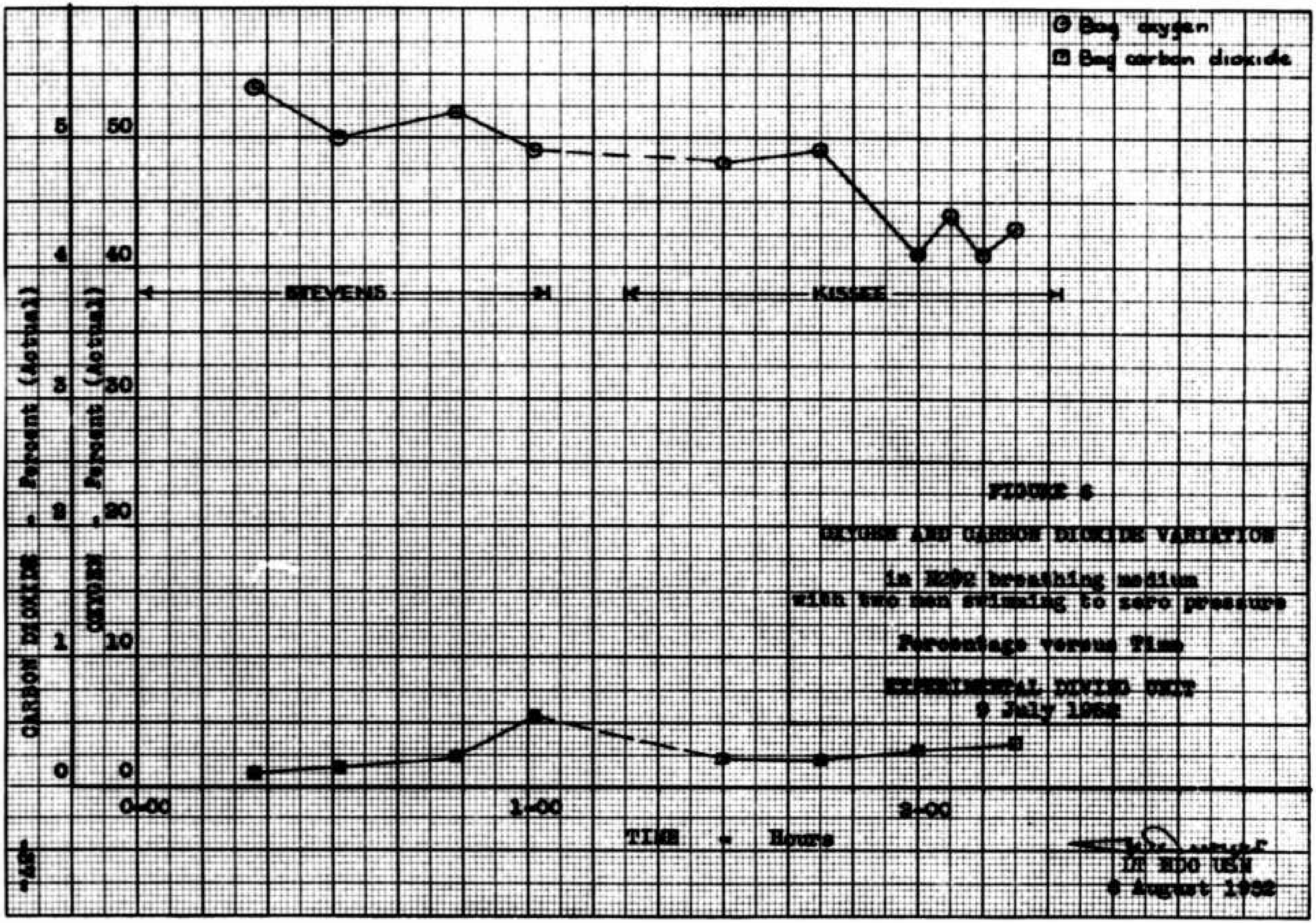
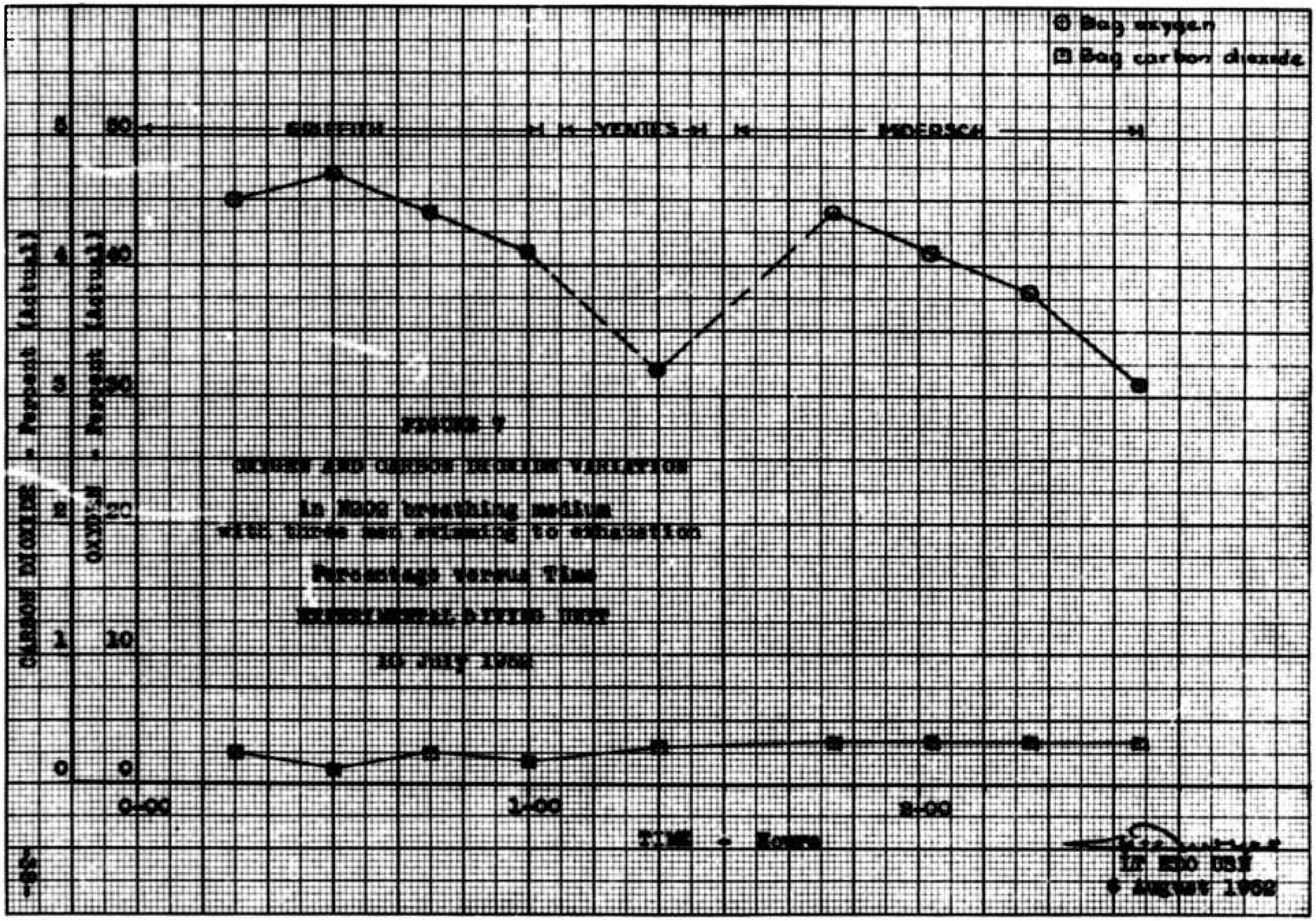


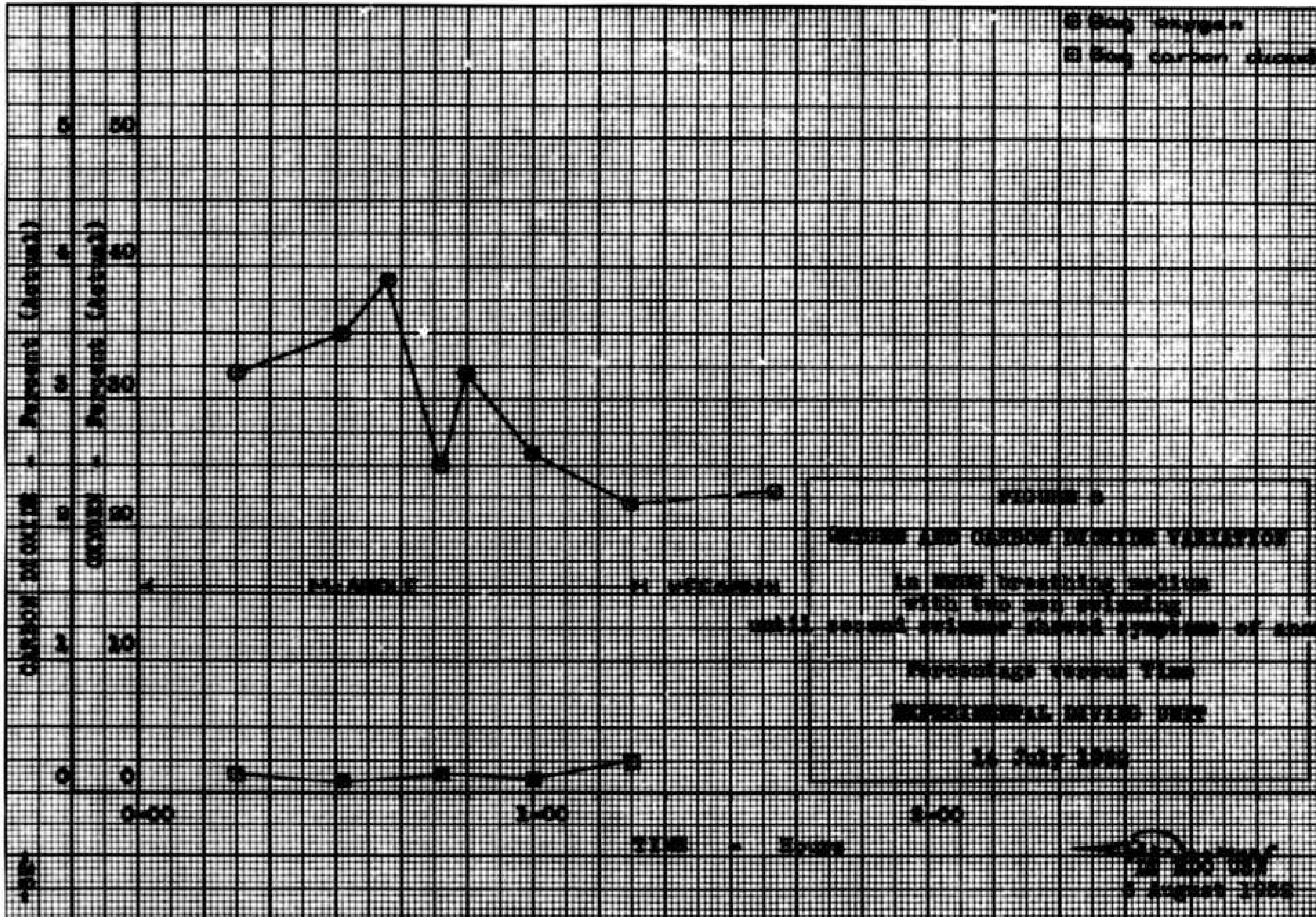
FIGURE 4
CARBON DIOXIDE RISE
EXPERIMENTAL DIVING UNIT
CARBON DIOXIDE - Percent (Actual)
0
1
2
3
4
6
McKENZIE
STEVENS
MOORE
0-00
1-00
2-00
TIME - Hours
6 August 1952

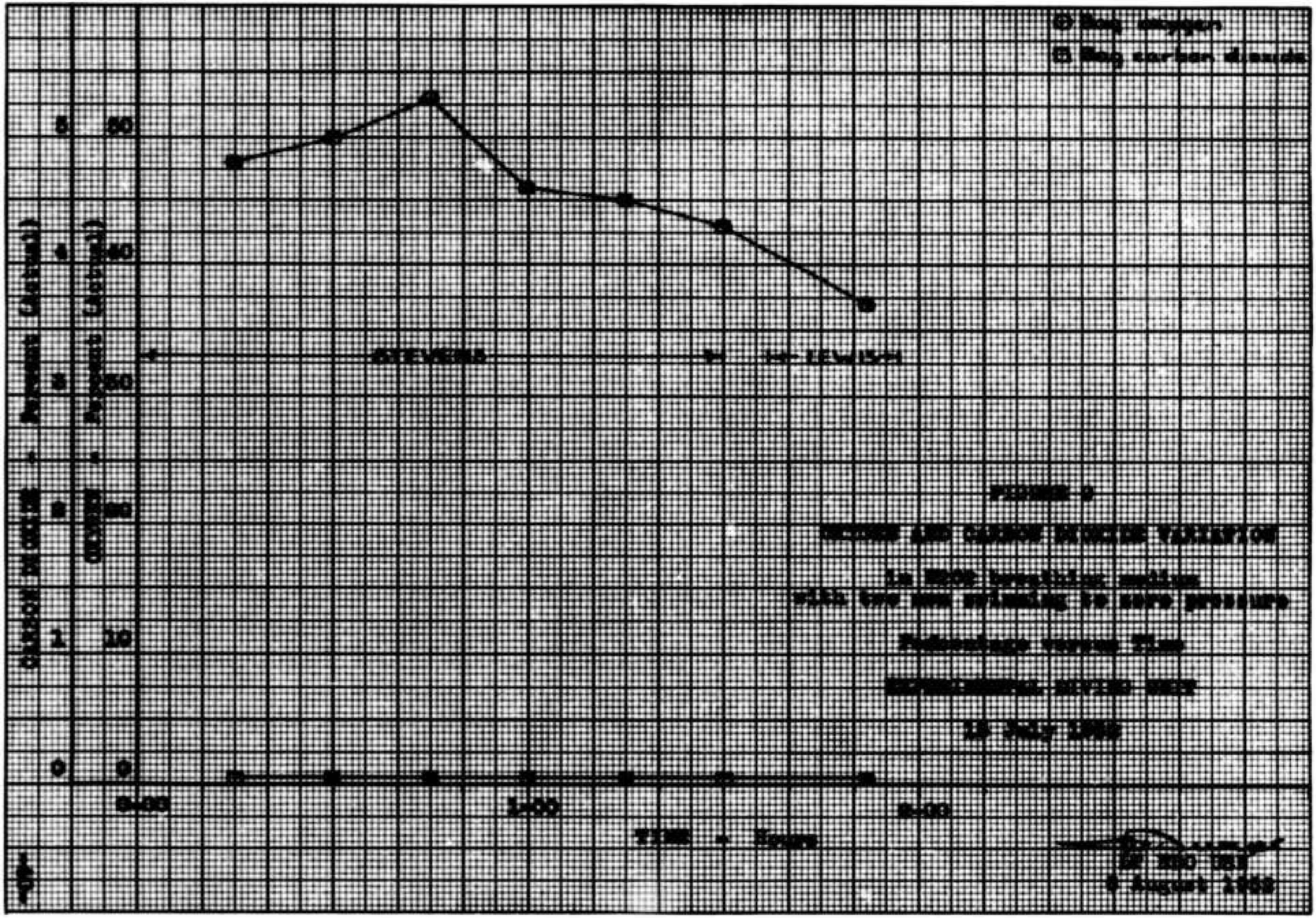

Percentage versus Time
EXPERIMENTAL DIVING UNIT
Bag oxygen
Probable oxygen peak
Bag carbon dioxide
McKENZIE
MOERSCH
CARBON DIOXIDE - Percent (Actual)
OXYGEN - Percent (Actual)
0-00
1-00
2-00
TIME - Hours
LT USN
August 1952



Bag oxygen
Bag carbon dioxide
CARBON DIOXIDE - Percent (Actual)
OXYGEN - Percent (Actual)
5
4
3
2
1
0
50
40
30
20
10
0
STEVENS
0-00
1-00
2-00
TIME - Hours
in N2O2 breathing medium
with two men swimming to zero pressure
Percentage versus Time
9 July 1952
August 1952


Bag oxygen
Bag carbon dioxide
GRIFFITH
YENTES
CARBON DIOXIDE - Percent (Actual)
OXYGEN - Percent (Actual)
0
1
2
3
4
5
0
10
20
30
40
50
0:00
1:00
2:00
TIME - Hours
OXYGEN AND CARBON DIOXIDE VARIATION
Percentage versus Time
EXPERIMENTAL DIVING UNIT
10 July 1962
LT MSC USN
August 1962


Bag oxygen
Bag carbon dioxide
CARBON DIOXIDE - Percent (Actual)
OXYGEN - Percent (Actual)
0
10
20
30
40
50
0+00
1+00
2+00
TIME - Hours
Percentage versus Time
EXPERIMENTAL DIVING UNIT


Bag oxygen
Bag carbon dioxide
STEVENS
LEWIS
TIME - Hours
0:00
1:00
2:00
0
10
20
30
40
50
1
2
3
4
5
July 1959
August 1959

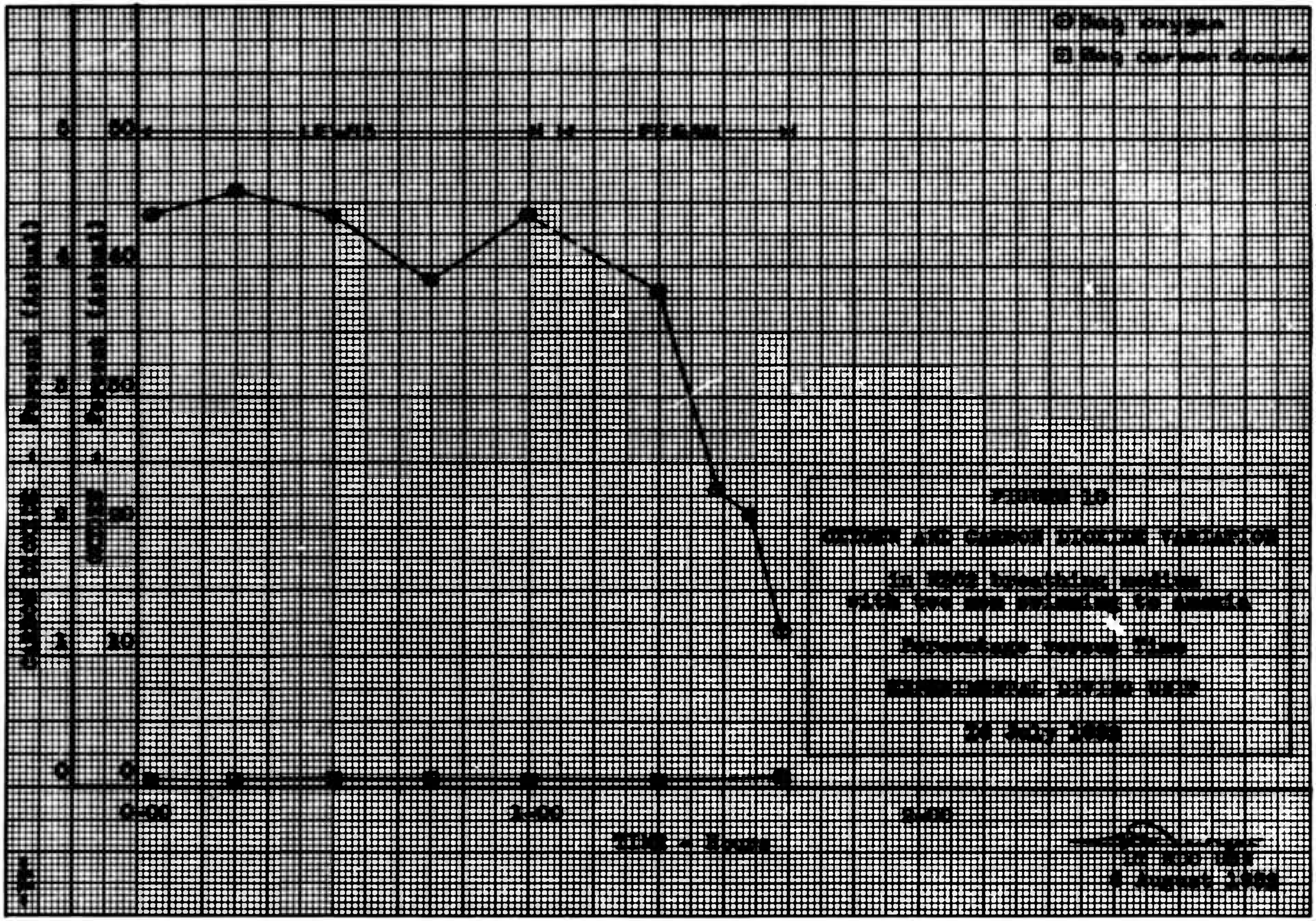


FIGURE 10

OXYGEN AND CARBON DIOXIDE VARIATION

Percentage versus Time

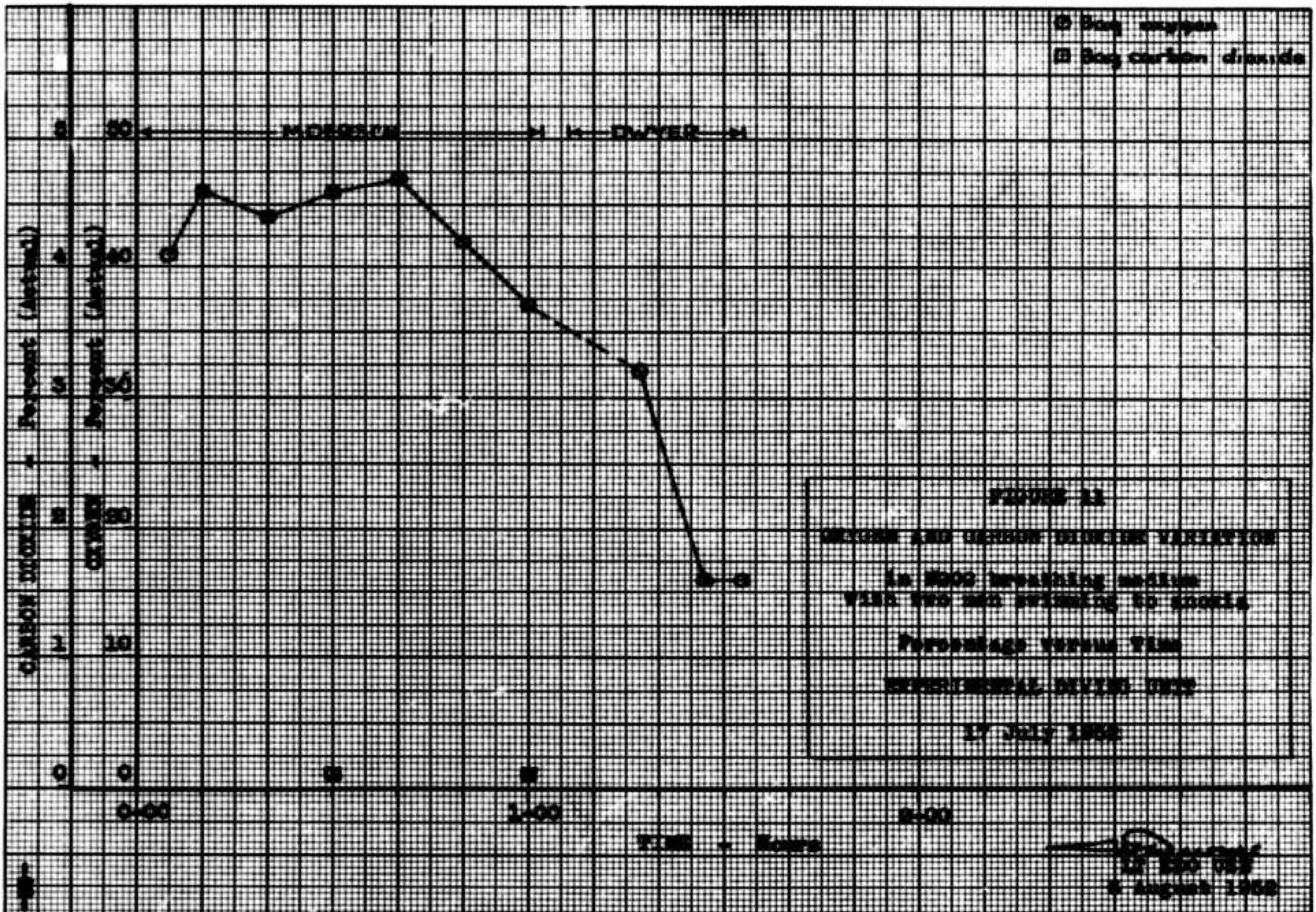


FIGURE 11

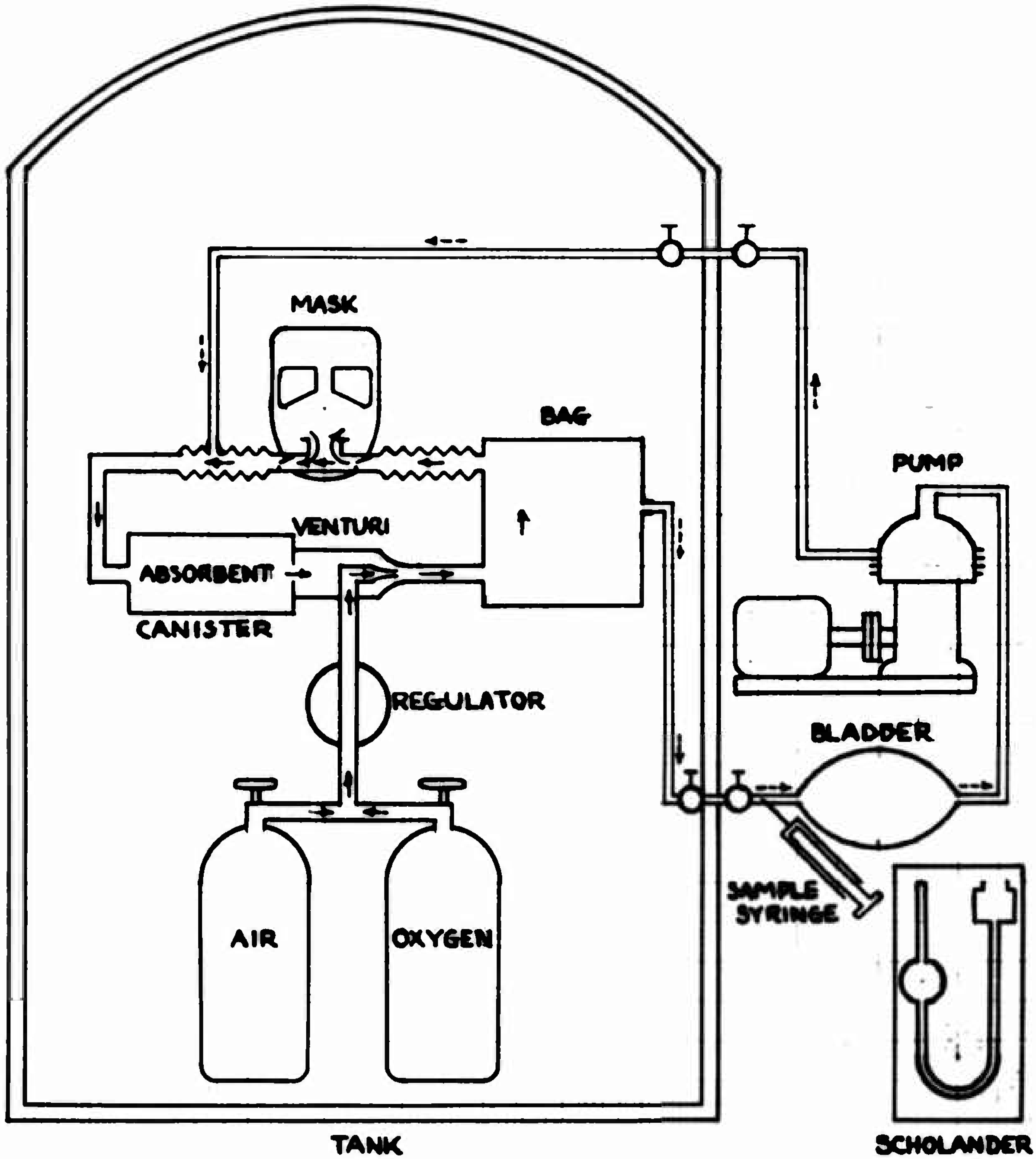
OXYGEN AND CARBON DIOXIDE VARIATION

in N_2O_2 breathing medium
with two men swimming to [illegible]

Percentage versus Time

EXPERIMENTAL DIVING UNIT

17 July 1958



SCHEMATIC OF RETURN-SAMPLING APPARATUS
for analysis of breathing medium under pressure, showing arrangement for bag oxygen sample in N2O2 SCUBA with sample returned to mask exhalation tube.

FIGURE 12

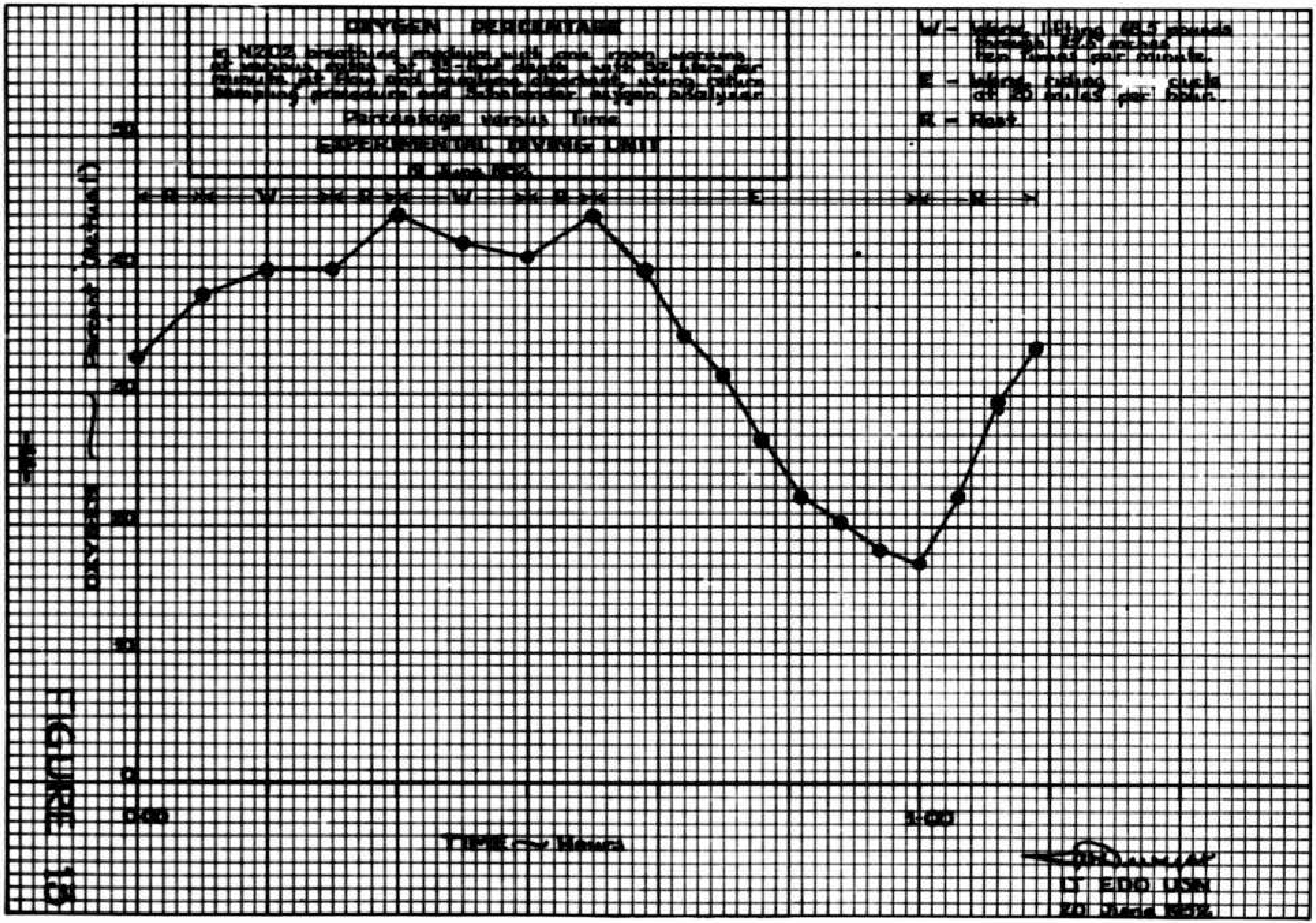
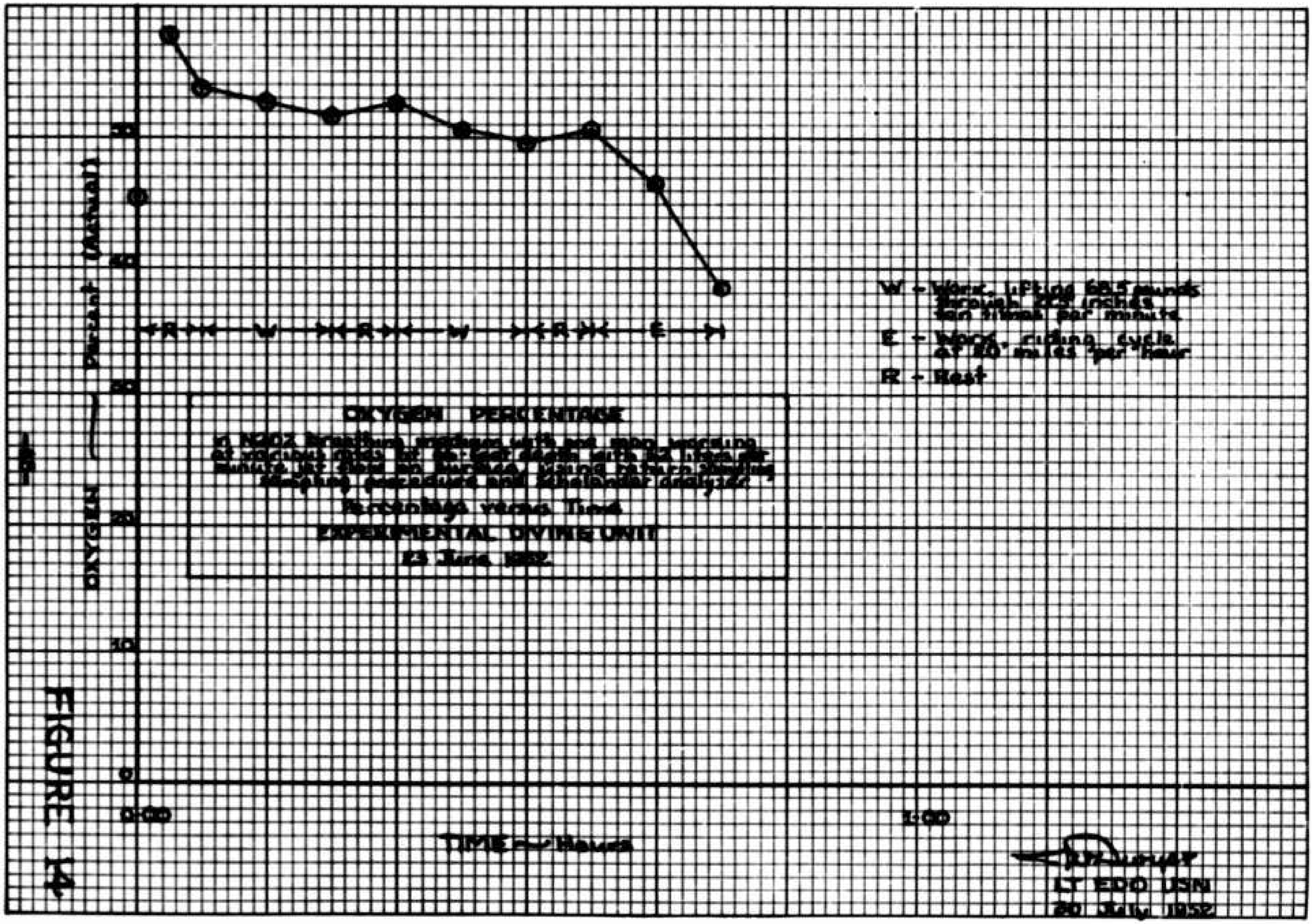

OXYGEN PERCENTAGE
Percentage versus Time
EXPERIMENTAL DIVING UNIT
R — Rest
OXYGEN ~ Percent (Actual)
50
40
30
20
10
0
0:00
1:00
TIME ~ Hours
LT EDO USN

FIGURE 15



OXYGEN — Percent (Actual)
OXYGEN PERCENTAGE
Percentage versus Time
EXPERIMENTAL DIVING UNIT
23 June 1952
E - Work, riding cycle at 20 miles per hour
R - Rest
TIME — Hours
0:00
1:00
LT EDO USN
20 July 1952

FIGURE 14

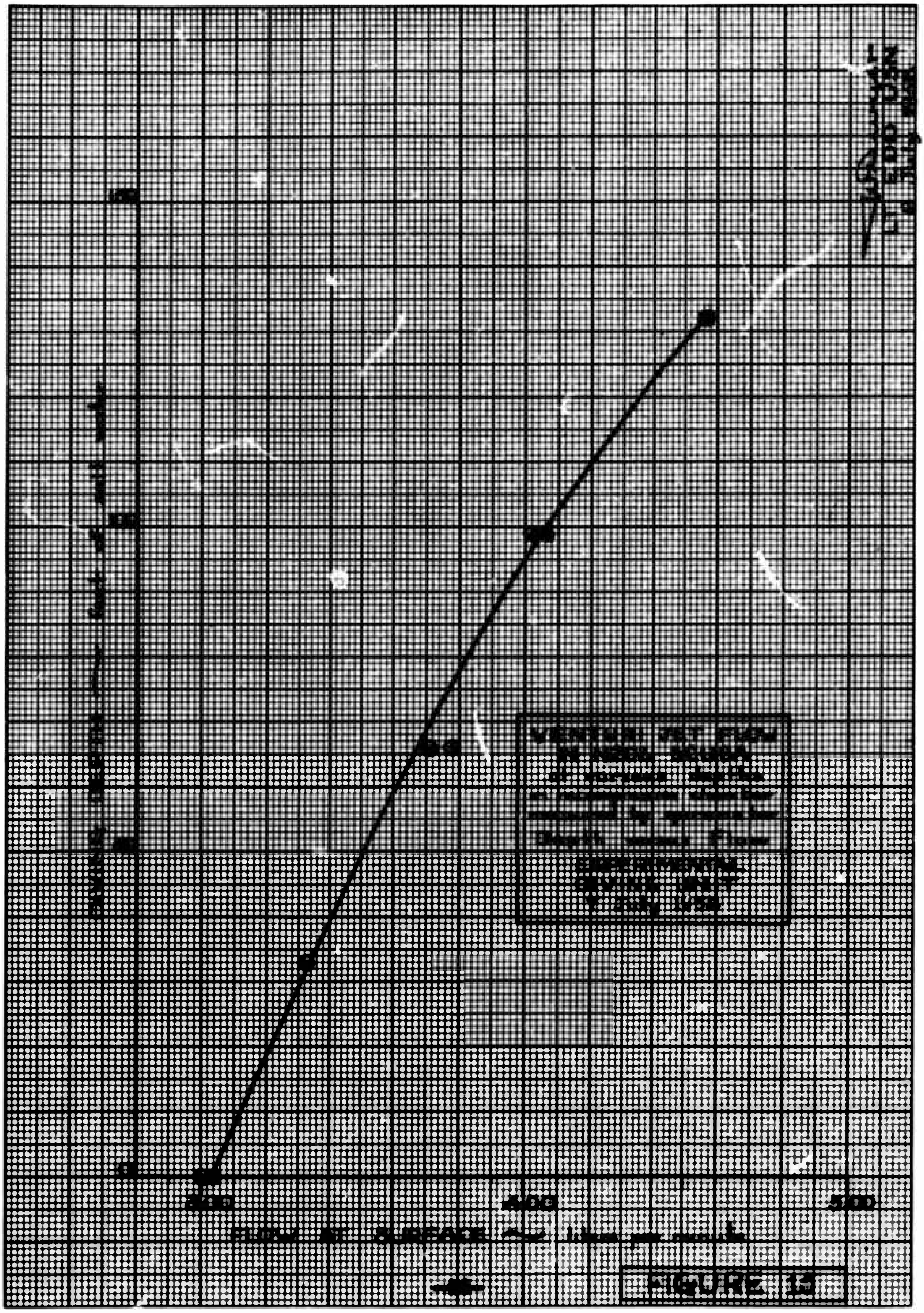


FIGURE 13

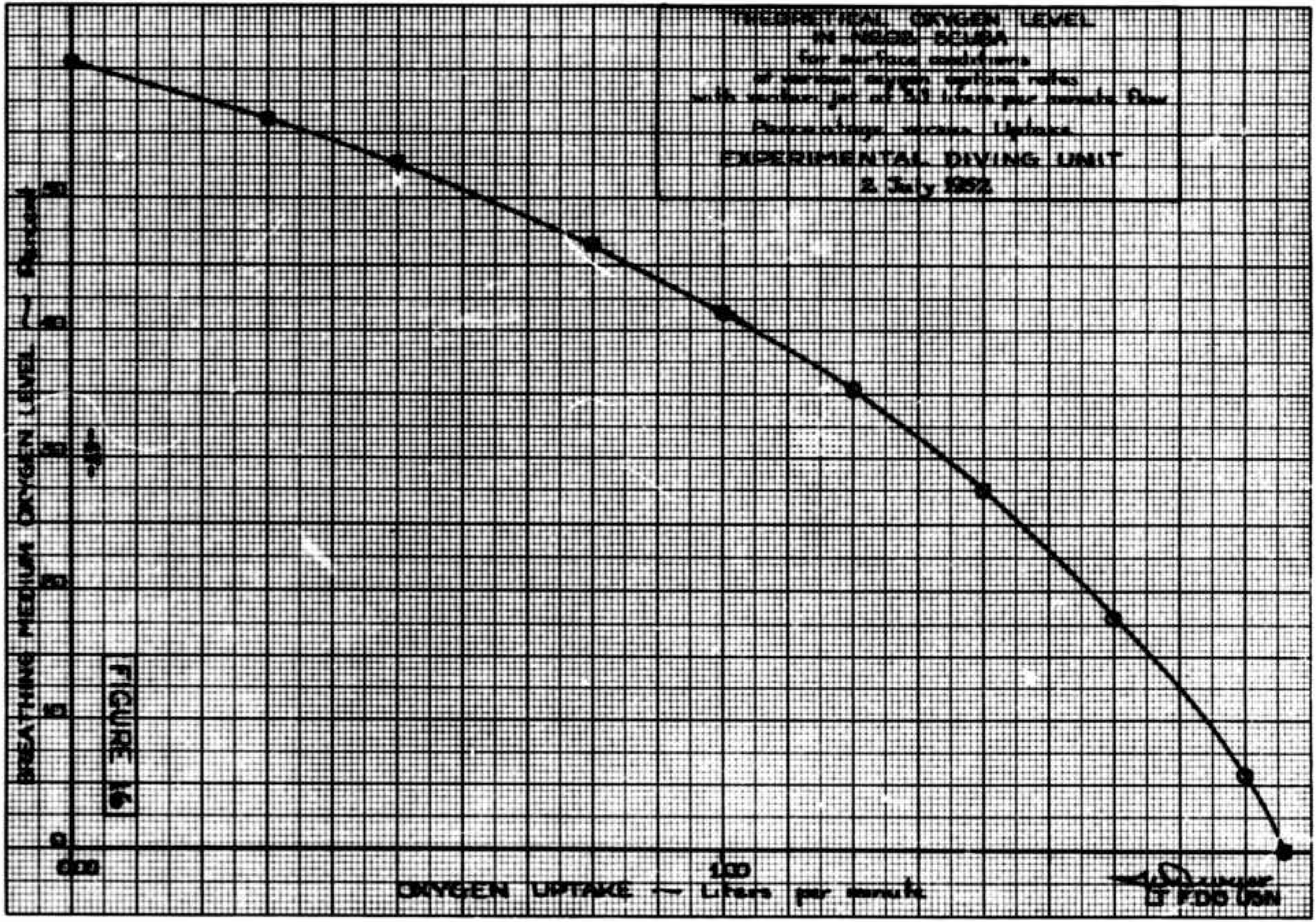

THEORETICAL OXYGEN LEVEL
for surface conditions
EXPERIMENTAL DIVING UNIT
2 July 1952
BREATHING MEDIUM OXYGEN LEVEL ~ Percent
OXYGEN UPTAKE — Liters per minute
100
LT PDD USN

FIGURE 16

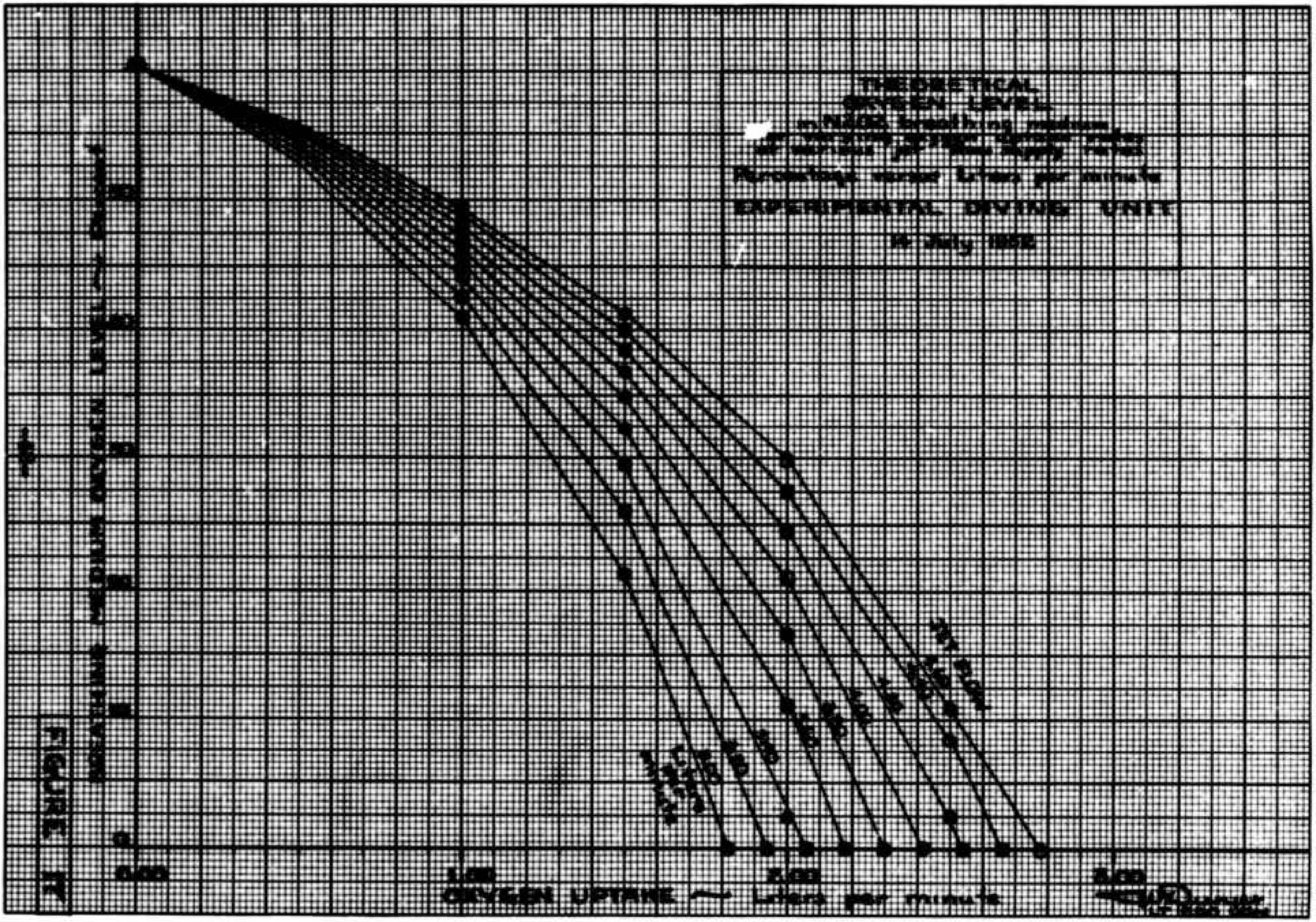

THEORETICAL
OXYGEN LEVEL
EXPERIMENTAL DIVING UNIT
OXYGEN UPTAKE ~ Liters per minute
BREATHING MEDIUM OXYGEN LEVEL ~ Percent
0.00
1.00
2.00
3.00

FIGURE 17